6-28-2001

Status of CIE color appearance models

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AIC Color 01 Rochester

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Outline

- Overview of Color Appearance Models
- History of CIECAM97s
- Ongoing CIE TC Activities
- Future Directions

What is a Color Appearance Model?

- Color appearance models extend basic colorimetry (XYZ) to predict the appearance of stimuli (*e.g.*, Lightness, Chroma, Hue) in a variety of viewing conditions.

- They account for changes in visual response due to changes in viewing environment.

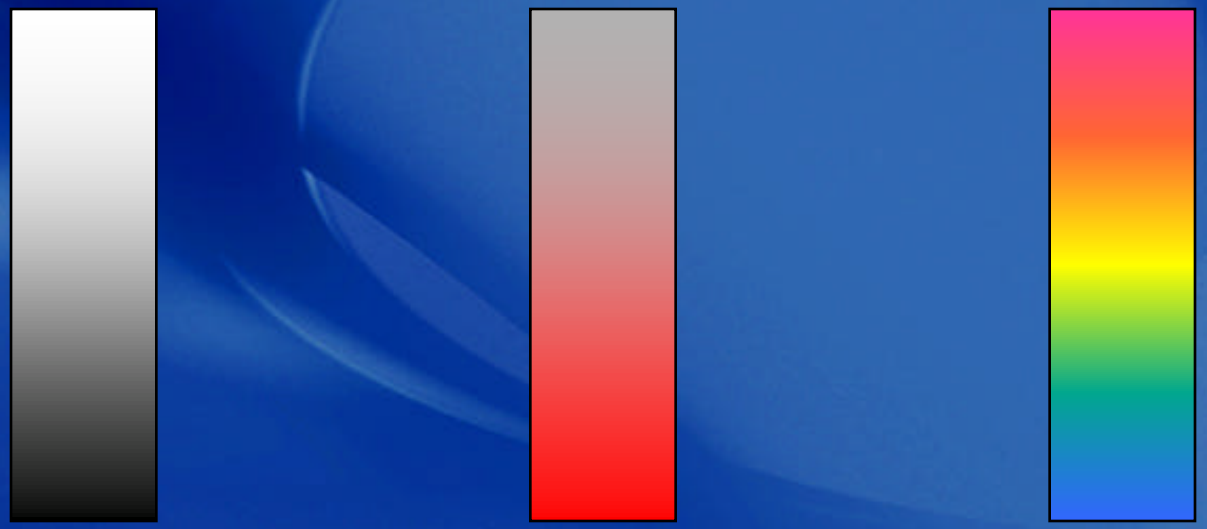
- These models are a tool.

What Does a Color Appearance Model Enable?

- Mapping from Measurements to Words (Physics to Perception)
- Prediction of Color Matches (or Changes) across Changes in Viewing Conditions

Appearance Correlates

- Brightness, Lightness
- Colorfulness, Chroma, Saturation
- Hue



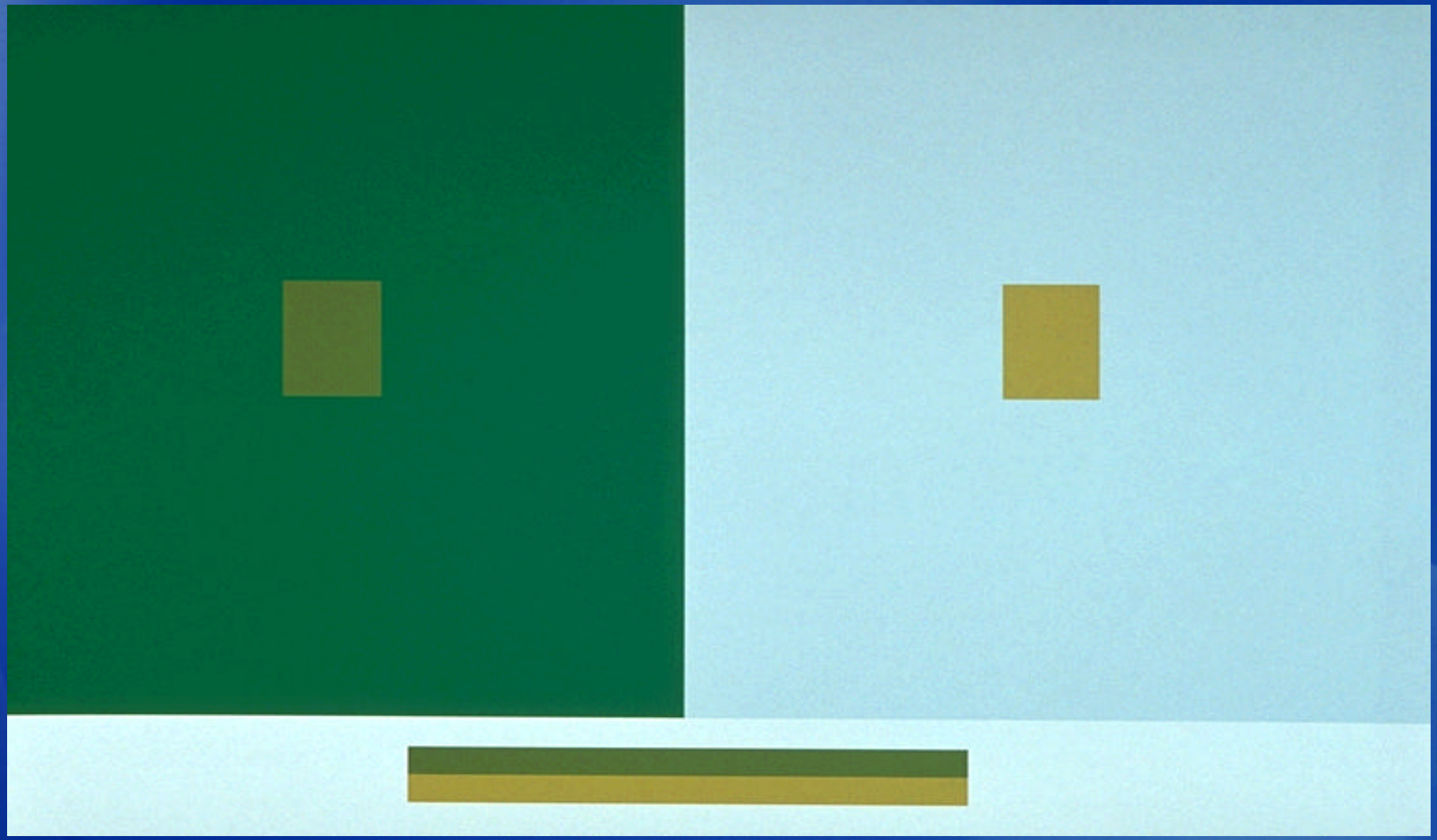
Color Appearance Phenomena

If two stimuli do not match in color appearance when $(XYZ)_1 = (XYZ)_2$, then some aspect of the viewing conditions differs.

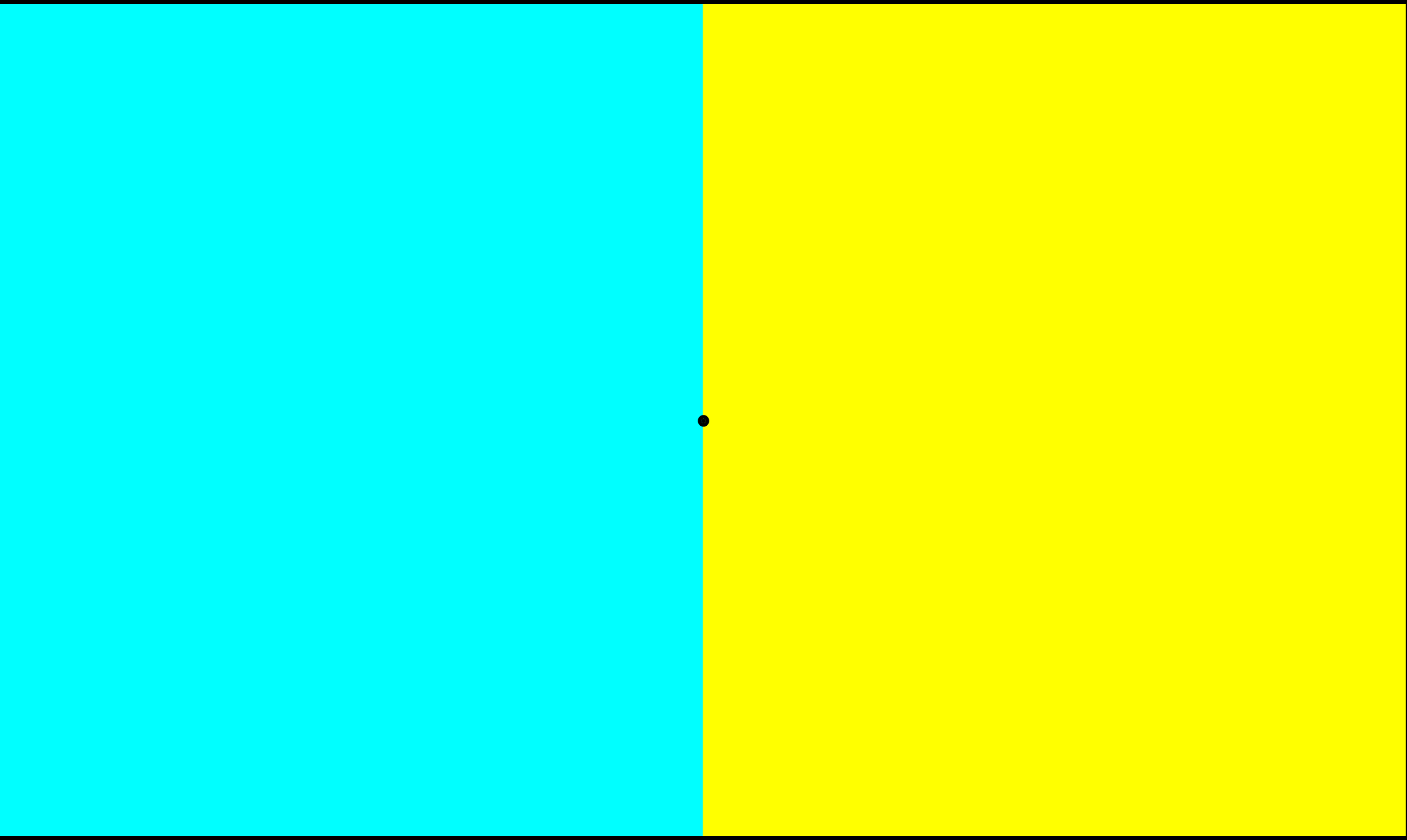
Various ***color-appearance phenomena*** describe relationships between changes in viewing conditions and changes in appearance.

(Stevens Effect, Hunt Effect, Simultaneous Contrast, Surround, Color Constancy, Memory Color, Discounting-the-Illuminant, Adaptation, etc.)

Josef Albers: Simultaneous Contrast



Chromatic Adaptation



Discounting-the-Illuminant

Putting it All Together

Components of a Color Appearance Model

(1) Chromatic Adaptation Transform

(2) Uniform Color Space

(3) Appearance Correlates

History of Color Appearance Models

1970's: CIELAB and CIELUV

Early 1980's: Initial Hunt and Nayatani Color Appearance Models

Late 1980's: Revisions of Hunt and Nayatani Models

Early 1990's: Model Testing, Further Revisions, New Models (*e.g.*, RLAB, LLAB)

Late 1990's: Convergence … CIECAM97s

Early 2000's: Widespread focused testing and refinement

CIECAM97s

- **CIE 1997 Interim Color Appearance Model (simple version)**
- An internationally agreed upon model that incorporates the best features of previously published models
- Current state-of-the-art, but undergoing refinement as expected (CIE TC8-01)

- *CIELAB is a simpler example of a color space that describes appearance.*

Where's CIECAM97c?

CIE 1997 Interim Color Appearance Model (comprehensive version)

- To be a fully comprehensive extension of CIECAM97s.
- No Apparent Demand
- Thus, Never Formulated

Work of CIE TC1-34

- CIE TC1-34, Testing Colour Appearance Models
- CIE Experts Symposium, Vienna, 1996
- Four Models Considered
- Kyoto, 1997
- CIECAM97s Born
- As good as the best
  in each situation.

Note: Authors of no less than 8 models served on the committee!!

The Formulation of CIECAM97s

- Use Good Parts from Existing Models
- Create a Consistently High-Performing Model
- Find a Single Model with Committee Consensus
- Simple and Comprehensive Versions
- Bradford CAT & Hunt Color Space

Expectations for CIECAM97s

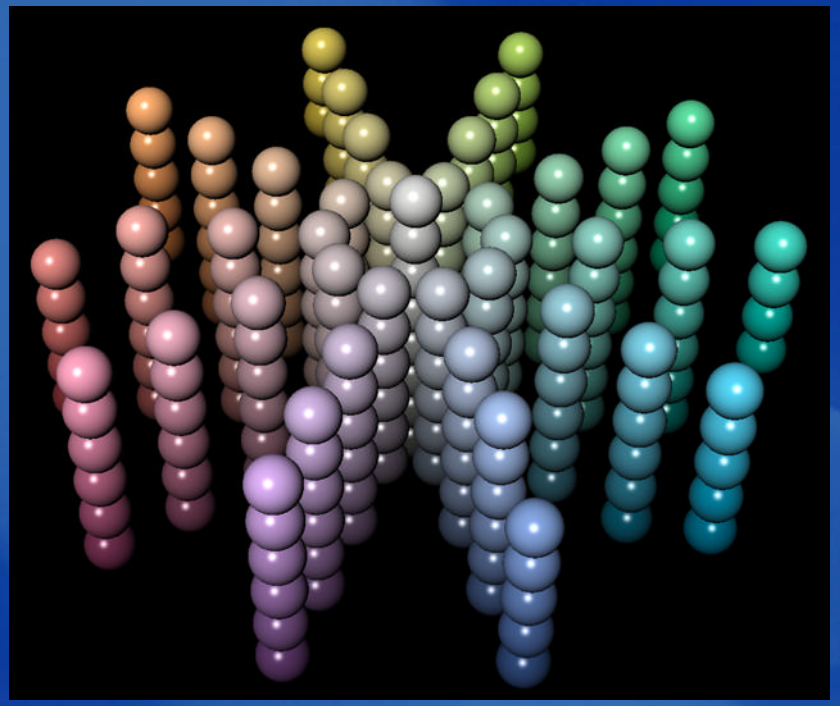
- Perform as Well as Best Model in All Circumstances
- Evolution, Not Revolution
- Interim, Continuous Improvement
- Basis for Comprehensive Model

CIECAM97s Chromatic Adaptation Transform

- Based on the Bradford CAT
  - An Extension of Bartleson
  - Incomplete Adaptation & Discounting Added
- von Kries on R & G
- Nonlinearity on B
- Unique XYZ-to-RGB Transform

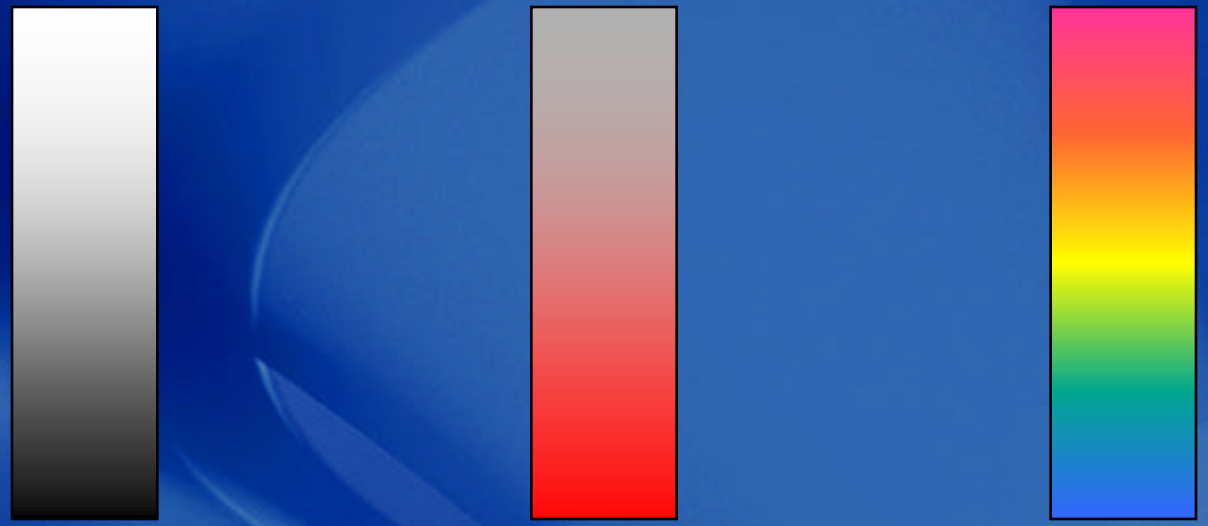
CIECAM97s Color Space

- Based on Structure within Hunt Model
- Enhancements Based on Various Tests, *etc.*
- Hyperbolic Nonlinearity
- Color Difference Signals
- Appearance Correlates



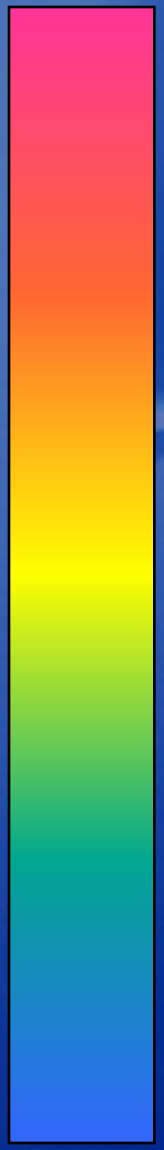
Appearance Correlates

- Brightness, Lightness
- Colorfulness, Chroma, Saturation
- Hue



- Built Up to Fit Experimental Data
- Need 5 of 6 to Fully Describe Appearance

Hue

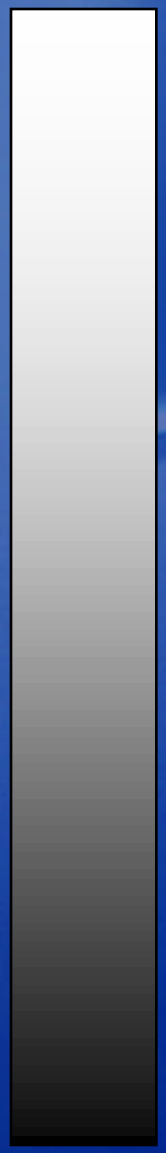


- The degree to which a stimulus can be described as similar to or different from stimuli that are described as red, green, blue, and yellow.

$$h = \tan^{-1}(b / a)$$

Red:	h = 20.14,	e = 0.8,	H = 0 or 400,
Yellow:	h = 90.00,	e = 0.7,	H = 100,
Green:	h = 164.25,	e = 1.0,	H = 200,
Blue:	h = 237.53,	e = 1.2.	H = 300

Lightness



- The brightness of a stimulus relative to the brightness of a stimulus that appears white under similar viewing situations.

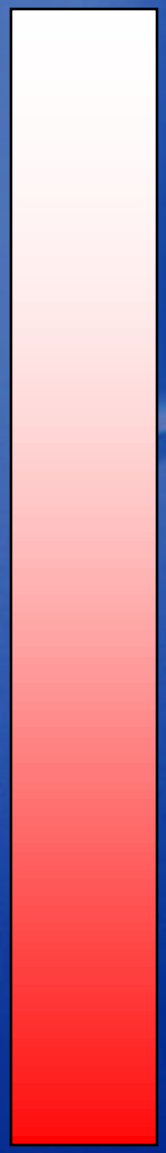
$$J = 100\left(A / A_w\right)^{cz}$$

Brightness

- The perceived quantity of light emanating from a stimulus.

$$Q = (124 / c)(J / 100)^{0.67}(A_w + 3)^{0.9}$$

Saturation



- The colorfulness of a stimulus relative to its own brightness.

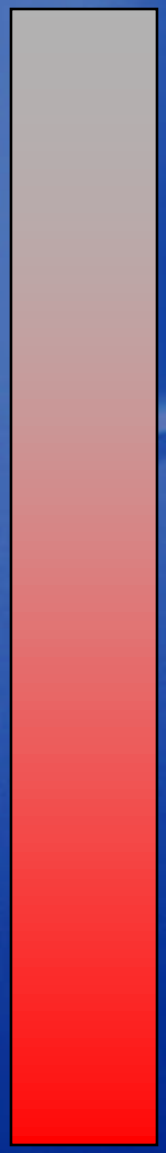
$$s = \frac{50\left(a^2 + b^2\right)^{1/2} 100e(10/13)N_c N_{cb}}{R'_a + G'_a + (21/20)B'_a}$$

Chroma

- The colorfulness of a stimulus relative to the brightness of a stimulus that appears white under similar viewing conditions.

$$C = 2.44 s^{0.69} (J/100)^{0.67n} (1.64 - 0.29^{n})$$

Colorfulness



- The perceived quantity of hue content (difference from gray) in a stimulus.
- Colorfulness increases with luminance.

$$M = CF_L^{0.15}$$

Active CIE Committees Related to Color Appearance

TC1-27, Specification of Colour Appearance for Reflective Media and Self-Luminous Display Comparisons

TC1-52, Chromatic Adaptation Transforms

TC8-01, Colour Appearance Modeling for Colour Management Applications

R1-24, Colour Appearance Models

CIE TC1-27, Specification of Colour Appearance for Reflective Media and Self-Luminous Display Comparisons

Chair: Paula Alessi, USA

Performing Visual Experiments to Assess the Performance of Various Models in these Applications

Final Report Expected Soon

(CIECAM97s Performs Reasonably Well)

CIE TC1-52, Chromatic Adaptation Transforms

Chair: M. Ronnier Luo, UK

Formulation of a CIE Chromatic Adaptation Transform

Unable to Reach Consensus

(Several Models Perform Equally Well)

CIE TC8-01, Colour Appearance Modeling for Colour Management Applications

Chair: Nathan Moroney, USA

Creating Implementation Guidelines
Revising/Improving CIECAM97s

Hard at Work, Revised Model Soon?

(Several Revisions Agreed Upon)

CIE R1-24, Colour Appearance Models

Reporter: Mark D. Fairchild, USA

Track and Report Activities to Div. 1

Make Recommendations for New TCs

Will Suggest TC8-01 Model be Endorsed by Div. 1

(Reporting to You Today!!)

Revision of CIECAM97s (TC8-01)

Fairchild, *Color Res. Appl.*, in press (2001).

- A Summary of Proposed Revisions
- Several Corrections to Formulation
- A Few Enhancements Proposed
- Additional Suggestions Have Been Made to TC8-01

Some Potential Changes

(1) Linearize Chromatic Adaptation Transform

(2) Fix Anomalous Surround Compensation

(3) Fix Lightness Scale for Perfect Black

(4) Reduce Chroma-Scale Expansion for Low-Chroma Stimuli

(5) Make Surround Compensation Continuously Variable

Maybe More…

Corrections

- Fix Anomalous Surround Compensation
- Fix Lightness Scale for Perfect Black

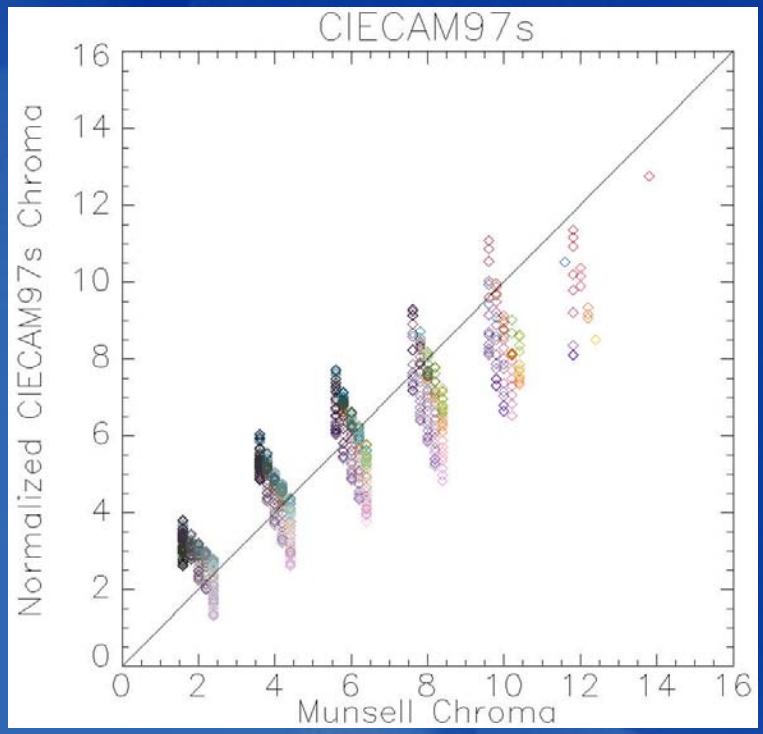
These have been discussed, used, and well-agreed upon. (*e.g.*, Li *et al. CR&A* (2000).)

Linearized Chromatic Adaptation Transform

- Linear CATs have been shown to perform as well as the nonlinear CAT in CIECAM97s
- Optimal Linear CATs can be derived by adjusting the XYZ-to-RGB Transform
- Several Researchers have come to similar conclusions (Li & Luo, Susstrunk & Finlayson, Fairchild)
- A Linear CAT Facilitates Model Inversion
- One Will be Included (which one???)

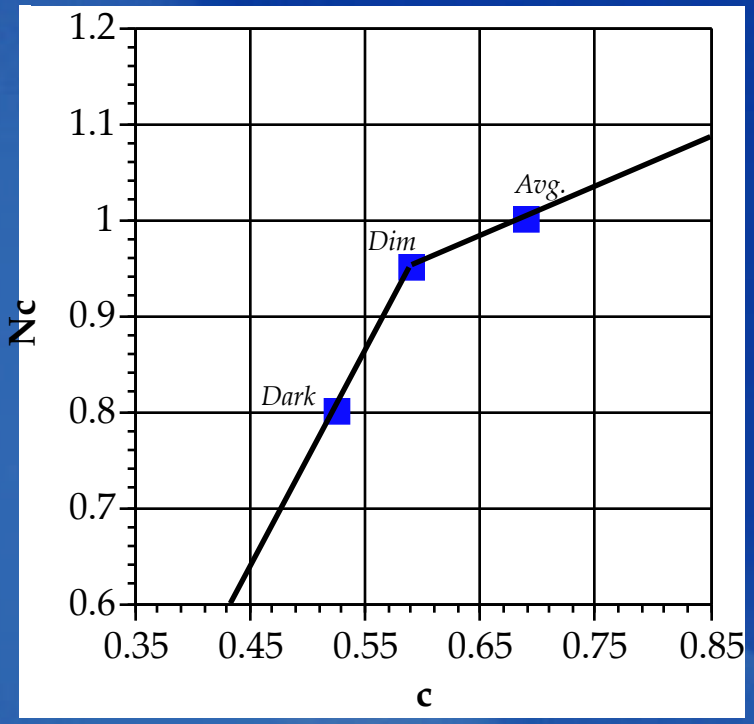
Chroma-Scale Expansion

- Several Researchers Have Suggested that the CIECAM97s Chroma Scale is Expanded for Low-Chroma Colors (Newman *et al.*, Moroney, Wyble & Fairchild)
- The Chroma Scale can be Easily Manipulated to More Closely Match Munsell Data and Reduce Image Processing Artifacts
- Inclusion of this Change is Still Being Discussed



Continuously-Variable Surround

- The Effect of Surround is Very Viewing Condition and Task Dependent
- It is Difficult to Quantify Predictively
- Continuously Variable Compensation Allows Fine Tuning
- Likely to be Included in Revision



Ongoing Work

- TC8-01 Considering These and Other Suggested Revisions
- Meeting this Saturday
- Goal to Formulate Draft Revision this Autumn
- CIE Div. 1 Endorsement?

Gratuitous Squishy Cow

Outlook / Future Directions

Perhaps CIECAM01s, or CIECAM02s, has been conceived, but not yet born.

CIE TC8-01 is making solid progress.

Further improvements beyond those will certainly be possible.

www.colour.org/tc8-01

www.cis.rit.edu/fairchild/CAM.html